

**METHOD AND APPRATUS FOR DELAY ADJUSTMENT
AND CHANNEL REORDERING IN BASEBAND
COMMUNICATION RECEIVING SYSTEM**

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FIELD OF THE INVENTION

10 [0001] This invention relates generally to delay adjustment and channel re-ordering, and particularly to a method and system for data forwarding, symbol alignment and pair-swap reordering in a base-band communication receiver system.

BACKGROUND OF THE INVENTION

15 [0002] In a high-speed data communication application, transmitted data may be modulated into a multi-dimensional bit stream format. In each dimension of the bit stream, a bit pattern for a symbol may be transmitted through one wire or one pair of wires. For example, in the situation where there are four pairs of wires at the transmission side, a 20 number or a symbol represented by one 8-bit data may be coded into four

couples of sub-symbols, each one representing an integer from -2, -1, 0, 1, and 2, and each one to be sent through one pair of wires. These four couples of sub-symbols are now representing the one symbol that was originally represented by the two 8-bit data.

5 [0003] At the receiving side, the four couples of sub-symbols will need to be decoded back to the original 8-bit format. However in a high-speed data communication system, these four pairs of sub-symbols may go through different wire delays and may therefore arrive at different clock cycles at a receiver system. Also, the four pairs of wires may be transposed
10 in a transmission channel, causing some pairs of sub-symbols to be swapped.

[0004] A receiver system usually processes the bit stream in several stages, including a front-end signal processing stage and a decoding stage. At the front-end signal processing stage, the bit patterns are typically processed one dimension at a time. The results are then forwarded to the
15 decoding stage. A conventional Viterbi decoder typically handles the decoding stage. However, the Viterbi decoder usually requires that the bit patterns in different dimensions be well aligned for the same symbol and the pair-swaps be reordered. This adds complexity to the design of the decoder stage in a receiver system.

[0005] Moreover, symbol alignment and pair-swap reordering operations typically require the use of many data buffers. Digital first-in-first-out buffers (“FIFO”) have been used for symbol level data synchronization. However, when multiple pairs of wires are involved, the 5 conventional FIFO structure becomes too simple for the reordering of the pairs of wires, and it cannot perform pair-swap reordering and symbol alignment at the same time. To solve the problem, many FIFO’s may operate in parallel to buffer the data. Since the FIFO’s are power-hungry and area-consuming components, using many FIFO’s for the symbol 10 alignment and pair-swap reordering operations in the receiver system becomes undesirably space demanding and power consuming.

SUMMARY OF THE INVENTION

[0006] The apparatus and method of present invention operates to 15 receive and process a multi-dimensional signal transmitted through a communication channel. The apparatus includes a slicer/encoder coupled to a pair-swap and symbol alignment module that outputs to a decoder. The encoder operates with the slicer, and uses a coding method that reduces the number of bits associated with each symbol in the multidimensional signal

as required to be passed through the pair-swap and symbol alignment module to the second decoder, while preserving the detailed code distance information. The pair-swap and symbol alignment module detects and corrects pair-swap and symbol misalignment in the multidimensional signal.

5 The decoder includes a first decoder and a second decoder. The first decoder operates to reverse the encoding done on the multidimensional signal by the encoder. The second decoder operates to correct errors occurred in the multidimensional signal during its transmission in the communication channel.

10 [0007] With the coding method, very compact yet sufficient information is passed through the pair-swap and symbol alignment module to the second decoder. Thus, the number of flip-flops in the pair-swap and symbol alignment module can be significantly reduced because of the reduced number of bits for each symbol. Furthermore, the pair-swap and 15 symbol alignment module performs symbol alignment and pair-swap reordering in one pass, and uses very high degree of serialization to further reduce the total number of flip-flops required. Therefore, power consumption and size of circuitry are significantly reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIGURE 1 is a block diagram of a digital receiver system in accordance with an embodiment of the present invention.

[0009] FIGURE 2 is a block diagram that illustrates the encoding 5 method used by the Encoder.

[0010] FIGURE 3 is a block diagram of a pair-swap and symbol alignment module in the digital receiver system in accordance with an embodiment of the present invention.

[0011] FIGURE 4A is a block diagram of a non-data mode 10 receiver in the symbol alignment module in accordance with an embodiment of the present invention.

[0012] FIGURE 4B is a flow chart illustrating a process for symbol alignment and pair-swap detection in the non-data mode receiver in accordance with an embodiment of the present invention.

15 [0013] FIGURE 4C is a circuit schematic of a hardware implementation of the non-data mode receiver in accordance with an embodiment of the present invention.

[0014] FIGURE 5A is a block diagram of a switchboard for pair-swap and symbol alignment adjustment in the pair-swap and symbol

alignment module in accordance with an embodiment of the present invention.

[0015] FIGURE 5B is a block diagram illustrating an example of a pair-swap reordering and symbol alignment operation performed by the 5 switchboard in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0016] Figure 1 is a schematic block diagram of a digital receiver system 100 for receiving and processing a digital signal 101 transmitted through a communication channel (not shown), in accordance with an 10 embodiment of the present invention. In one embodiment of the present invention, the digital signal 101 is a multi-dimensional bit stream coming through 4 pairs of wires, which are wire-pairs A, B, C, and D. The digital signal 101 includes a non-data part, $\{A_n[0], B_n[0], C_n[0], D_n[0]\}$, and a data part, $\{A_n, B_n, C_n, D_n\}$. The non-data part arrives before the data part 15 and is used by the digital receiver system 100 to detect and correct any pair-swap or alignment skew in the four pairs of wires before connection with the data part of the input signal is established. The digital receiver system 100 includes a channel equalizer 115 for minimizing the effect of channel

distortion on the digital signal 101. The channel equalizer 115 further includes a feed-forward equalizer (“FFE”) 110, a decision feedback equalizer (“DFE”) 120, and a slicer/encoder 130. The slicer/encoder 130 quantizes the input signal 101 on each wire or pair of wires to a modulation

5 format. One example of such a modulation format is the pulse amplitude modulation (PAM) format, such as PAM5, in which the signal on each wire or pair of wire is modulated into five levels, such as 2, 1, 0, -1, and -2.

Digital data associated with a sub-symbol in a modulation format, such as PAM5, typically does not carry any distance or neighborhood information as

10 later described herein with reference to Figure 2, and is therefore too concise for a Viterbi decoder to use for its decoding purposes. Therefore, in one

embodiment of the present invention, the slicer/encoder 130 also encodes the modulated data and the neighborhood information for each sub-symbol into

a 5-bit encoded pulse amplitude modulated format (“EPAM5”), so that very

15 compact yet sufficient information will be carried through subsequent

processing steps.

[0017] The receiver system 100 further includes a pair-swap and symbol alignment module 150 that receives the sliced and encoded data from the slicer unit 130, and performs pair-swap reordering and symbol

alignment operation on the received data. The receiver system 100 further includes a decoder comprising an EPAM5 decoder 180 and a Viterbi decoder 190 coupled to the EPAM5 decoder 180. The EPAM5 decoder decodes data in EPAM5 format to recover the neighborhood information for

5 each sub-symbol and expands the 5 bits encoded data for each sub-symbol into a 9-bit format for Viterbi decoding. The Viterbi decoder 190 corrects any errors such as noise caused by the communication channel in the decoded data from the EPAM5 decoder 180, and produce an output signal 102 of the digital receiver system, which are in the 8-bit format for each 10 symbol. After going through the pair-swap and symbol alignment module 150, the encoded sub-symbols in the four pairs of wires are aligned and any pair-swaps in the four pairs of wires are reordered. The symbols are then sent to the EPAM5 decoder 180 through 4 ordered data lines in the order of line W, line X, line Y, and line Z.

15 [0018] The receiver system 100 operates compatibly with conventional protocols and includes a scrambler coefficient generator 170 for providing the pair swap and symbol alignment unit 150 with coefficients required by the pair-swap reordering and symbol alignment operation. The scrambler coefficient generator 170 uses the non-data part of the input signal

in the first wire-pair, wire-pair A as a random sequence generator to log on a seed transmitted from a transmission side. The seed is then used to generate a set of scrambler coefficients, $Scn[3:0]$, which will be used to compare with the non-data part of the input signal 101 in wire-pairs B, C, and D, for the 5 purpose of detecting pair-swap and symbol misalignment. The scrambler coefficients, $Scn[3:0]$, are synchronized with wire-pair A, so that any misalignment detected will be with respect to the symbols in wire-pair A. The A-select input is provided from an analog front-end circuit (not shown), and a control unit (not shown) synchronizes and controls the operation of the 10 different units in the digital receiver system 100 in the manner as later described herein.

[0019] Reference is now made to Figure 2 to describe a method used by the slicer/encoder 130 to encode the digital signal 101 into EPAM5 format, in accordance with one embodiment of the present invention. The 15 input to the slicer/encoder 130 may be some fixed-point format and the slicer directory converts the signal into the EPAM5 format. Figure 2 shows EPAM5 and conventional F3.3 format characteristics. The slicer/encoder 130 extracts the sign bit, the second magnitude bit, and the first fractional bit as the content that will be used to decide to which signal level the data

belongs. The raw distance information for the Viterbi decoder 190 is in the 3 fractional bits. The slicer/encoder further employs a set of EPAM5 class assignment 220 and a distance metric 250 corresponding to the raw bias information for the PAM5 output. The class assignment 220 and the

5 distance metric 250 are used to encode the PAM5 output and the corresponding neighborhood information, as shown in the PAM5-A-B column 240, into five bits. If the input data in the F3.3 format is greater than 2, then the encoding method automatically generates 011 for the EPAM5 class assignment 220. The first digit of each of the numbers in the PAM5-
10 A-B column represents the PAM5 output from the slicer unit 130. The digits in the A and B columns represents the neighbors in the A class and the B class, respectively, (i.e., signal levels of {2,0, -2} is the “A” class, and signal levels of {1, -1} is the “B” class). The PAM5-A-B neighborhood information will be extracted at the EPAM 5 decoder 180.

15 [0020] The Slicer Encoder 130 extracts the sign bit, the second magnitude bit, and the factual bits and encode these bits into the EPAM5 format. These 5 bits can carry the PAM5 information, the neighbor information and the distance metric information for the Viterbi decoding performed later by the Viterbi decoder 190. Table 1 lists a few examples of

how data associated with a sub-symbol in F3.3 format is converted to EPAM5 format.

Table 1. Examples of EPAM5 Encoding

F3.3	Class Assignment	PAM5-A-B	Distance Metric	EPAM5
001.101	001	2 21	101	01101
010.100	010	2 21	100	00100
100.010	100	-2-2-1	010	10010
110.001	110	-2-2-1	001	10001

5 [0021] Referring now to Figure 3, there is shown a block diagram of the pair-swap and symbol alignment module 150 in the digital receiver system 100 of Figure 1, in accordance of an embodiment of the present invention. The pair-swap and symbol alignment module 150 takes the encoded signal from the slicer/encoder 130 as input and performs pair-swap

10 reordering and symbol alignment on the encoded signal before outputting the signal to the EPAM5 decoder 180. The pair-swap and symbol alignment module 150 includes a non-data mode receiver or a pair-swap and symbol alignment detection unit 355 that receives the non-data part of the input signal 101 and detects pair-swap and alignment skew in the input signal 101.

15 The pair-swap and symbol alignment module 150 further includes a switchboard or pair-swap and symbol alignment adjustment unit 357 that is

coupled to the non-data mode receiver 355. The switchboard 357 performs the operation of symbol alignment and pair-swap reordering on the encoded signal before verifying that the pair-swap and symbol alignment skew detected by the non-data mode receiver 355 are correct. The pair-swap and

5 symbol alignment module 150 further includes an EPAM5-to-binary converter 353 that is coupled to the non-data mode receiver 355 and the switchboard 357. The EPAM5-to-binary converter 353 converts the non-data part of the encoded signal to a binary format for pair-swap and symbol alignment detection and verification purposes. The pair-swap and symbol
10 alignment module 150 further includes a seed line selector 351 for selecting the seed line which is used as a reference for pair-swap and symbol alignment adjustment.

[0022] Referring now to Figure 4, there is shown a block diagram of the non-data mode receiver 355, in accordance with an embodiment of the
15 present invention. The non-data mode receiver 355 includes three FIFO buffers 420 for loading binary data from the EPAM5-to-binary converter 353, and a set of parallel loadable buffers 423 that parallelly loads the scrambler coefficients from the scrambler coefficient generator 170 and serially shifts the loaded scrambler coefficients through shift register 424 for

comparison with selected binary data from the three sets of FIFO buffers

420. The non-data mode receiver 355 further includes three selecting

devices (or selectors), 410B, 410C, and 410D. Selector 410B is configured

to select from the output of the EPAM5-to-binary converter 353 data

5 associated with wire-pair B; selector 410C is configured to select from the

output of the EPAM5-to-binary converter 353 data associated with wire-pair

C; and selector 410D is configured to select from the output of the EPAM5-

to-binary converter 353 data associated with wire-pair D. The non-data

mode receiver 355 further includes a comparison unit 460 configured to

10 compare selected data from the FIFO buffers 420 with a set of scrambler

coefficients from the parallel loadable buffers 423. The comparison unit 460

makes use of three pair-swap and symbol alignment registers 470B, 470C,

and 470D for locking in the pair-swap and symbol alignment skew detected

for the wire-pairs B, C, and D, respectively.

15 [0023] In one application of the present invention, each of the

FIFO buffers 420 is 16 bits in size, and every other bit from each FIFO

buffer 420 is selected to fit an 8-bit format required by the Gigabit protocol

(IEEE 802.3ab standard). For this application, the non-data mode receiver

355 further includes three even/odd selectors 440B, 440C, and 440D, each

for selecting from one of the FIFO buffers 420 every other bit of data with even or odd time stamps for comparison. Therefore, the even/odd selector 440B, 440C, or 440D sends two sets of data separately to the comparison unit 460 for comparison with the scrambler coefficients, one set of data

5 having even time stamp, one set of data having odd time stamp. The even/odd selectors 440B-D make use of an even/odd decoder 450 for determining the even or odd feature of each set of data. The even/odd decoder 450 determines the even or odd feature of each set of data from one FIFO buffer 420 at a time, and therefore makes use of a selecting device 430

10 that selects data sent through one of the three data buses 423. The even/odd decoder 450 also makes use of three even/odd registers 455B, 455C, and 455D for locking in the even/odd features determined for the data from the three FIFO buffers 420, respectively. The non-data mode receiver 355 further includes three data buses 421 coupled to the three FIFO buffers 420,

15 respectively, for transporting data from the FIFO buffers 420 to the three even/odd selectors 440B, 440C, and 440D, respectively. The non-data mode receiver 355 further includes three other data buses 422 that are connected to the three data buses 421, respectively. The three buses 422 transport data from the FIFO buffers 420 to the even/odd decoder 450. (In other

applications, the even/odd selectors 440B-D, the even/odd decoder 450, the selector 430, the data buses 422 and the even/odd registers are not required. Data may be directly taken from the FIFO buffers 420 to the comparison unit 460 for comparison with the scrambler coefficients.)

5 [0024] Reference are now made to Figures 4A and 4B to describe the operation of the non-data mode receiver. The receiver receives four pairs of data coming ion wire-pairs A, B, C, and D. Based on the output of the seed line selector 351, as shown in Figure 3 the non-data mode receiver 355 selects data from wire-pair A as reference for alignment. Then data 10 from the other three pairs of wires are loaded into the three FIFO buffers 420, respectively, at the same time. The scrambler coefficients, $Scn[3:0]$, are parallelly loaded into the parallel loadable buffers 423. The parallel loadable buffers includes a shift register 424 that serially shifts the coefficients to the comparison unit 460. 8 bits of coefficient data are pulled 15 out to the comparison unit 460 at a time.

[0025] The comparison unit 460 uses the 8 bits of coefficient data to compare with an 8-bit set of data with even or odd time stamp from each of the three FIFO buffers 420. Once there is a match, it is considered as a hit. This is done for data associated with each of the three different pairs of

wires loaded in the FIFO buffers 420, in order to find the pair-swap and alignment information for the three wires. The comparison is done in a serial manner, i.e., first data associated with wire-pair B is taken for

comparison, then wire-pair C, and then wire-pair D. Therefore, the

- 5 comparison for all three wire-pairs are broken into three cycles. Once there is a hit, meaning that a set of data with even/odd time stamp associated with one of the three wire-pairs B, C, or D match the 4-bit scrambler coefficient, the pair-swap and symbol alignment information is recorded in the respective pair-swap and alignment registers, 470B, 470C, or 470D. Until a
- 10 match is found for every one of the three pairs of wires, this process is repeated every three cycles, i.e., the scrambler coefficients are shifted by one bit every three cycles for comparison with data from the three wire-pairs.

When the pair-swap and symbol alignment information is found for all of the three pairs of wires, the even/odd feature of each set of data that matched

- 15 the scrambler coefficients is checked, and if it is different from the even/odd feature of wire-pair A, adjustment is made. As an example, the final pair-swap and symbol alignment information for wire-pairs B, C, and D may be, respectively, B = (Y, 2), meaning that B is ahead of A by two time stamps and should be switched to line Y, C = (Z, 4), meaning that C is ahead of A

by 4 cycles and should be switched to line Z, and D = (X, -2), meaning that

D is delayed in respect to A by 2 cycles and should be switched to line X.

[0026] By loading the scrambler coefficients parallelly and by shifting them serially, the comparisons are done in a serial manner, and the 5 comparison unit 460 is shared by the data from three pairs of wires. This serialization helps to reduce power consumption and size of hardware implementation because less circuitry is operated at the same time.

Figure 4C is a circuit schematic illustrating a hardware implementation of one embodiment of the non-data mode receiver 355 for 10 operating in the manner as described previously herein with reference to Figure 4A.

[0027] Reference is now made to Figure 5A and Figure 5B to describe the operation of the switchboard 357, in accordance with an embodiment of the present invention. Once the pair-swap and symbol 15 alignment information is found, Data from the slicer/encoder is sent to the switchboard 357 that reorders the swapped pairs and realign the symbols in the four pairs of wires. As shown in Figure 5A, the switchboard includes four FIFO buffers 520, and four symbol alignment adjustment units 521 attached to the four FIFO buffers, respectively. The four symbol alignment

adjustment units 521 are connected to the non-data mode receiver 355 (connection not shown), receive the symbol alignment information detected by the non-data mode receiver 355, and use that information to adjust the alignment of the symbols carried by the four pair of wires. The switchboard 5 also includes four pair-swap switching units 540W, 540X, 540Y, and 540Z, each one is coupled to the four symbol alignment adjustment units 521. The four pair-swap switching units 540W-Z are connected to the non-data mode receiver 355 (connection not shown), receive the pair-swap information detected by the non-data mode receiver 355, and use that information to re-order data from the four pairs of wires.

[0028] Still referring to Figure 5A, in one embodiment of the present invention, the switchboard 357 also functions to verify the correctness of the pair-swap and symbol alignment information detected by the non-data mode receiver 355. Therefore, the switchboard 357 also 15 includes four selectors 510A, 510B, 510C, and 510D for selecting between the data part and a combination of the scrambler coefficient and the non-data part of the input signal associated with wire-pairs A, B, C, and D, respectively. Each selector of the four selectors 510A, 510B, 510C, and 510D outputs to a different one of the four FIFO buffers 510. The

switchboard 357 further includes a second set of four selecting devices 506A, 506B, 506C, and 506D, coupled to the selectors 510A, 510B, 510C, and 510D, respectively. The selector 506A selects from the output of the slicer/encoder 130 data associated with wire-pair A; the selector 506B

5 selects from the output of the slicer/encoder 130 data associated with wire-pair B; the selector 506C selects from the output of the slicer/encoder 130 data associated with wire-pair C; and the selector 506D selects from the output of the slicer/encoder 130 data associated with wire-pair D. The switchboard 357 further includes a third set of four selecting devices 505A,

10 505B, 505C, and 505D, coupled to the selectors 510A, 510B, 510C, and 510D, respectively. The selector 505A selects from the output of the EPAM5-to-binary converter 353 data associated with wire-pair A; the selector 505B selects from the output of the EPAM5-to-binary converter 353 data associated with wire-pair B; the selector 505C selects from the EPAM5-

15 to-binary converter 353 data associated with wire-pair C; and the selector 505D selects from the output of the EPAM5-to-binary converter 353 data associated with wire-pair D. The switchboard further includes a descrambler seed and symbol comparison unit 550 that performs the operation of

comparing the symbol aligned and pair-swap reordered data with the scrambler coefficients.

[0029] The FIFO buffers 520 can be implemented by a series of flip-flops. In one embodiment of the present invention, each flip-flop is 5-
5 bits in size for holding one EPAM5 encoded sub-symbol. The number of flip-flops in each of the FIFO buffers 520 is flexible and can be adjusted according to the needs of particular applications.

[0030] The switchboard 357 operates in a verification mode and in a switching mode. In the verification mode, binary data associated with 10 the non-data part of the input signal for four wire-pairs are loaded into the four FIFO buffers 520, respectively. At the same time, scrambler coefficients from the different scrambler coefficient generator 170 are also loaded in the four FIFO buffers. Each of the 5-bit flip-flops holds one bit of data and four bits of scrambler coefficients. The symbol alignment 15 adjustment units 521 aligns the data by buffering the faster data longer and by jumping the slower data in respect to data from wire A, based on the pair-swap and symbol alignment information received from the non-data mode receiver. The scrambler coefficients and the aligned data are sent to each of the pair-swap switch units 540W-Z. The pair-swap switch unit 540W

selects from the data associated with the four wire-pairs data associated with wire-pair A and sends the data down line 542W to the descrambler seed and symbol comparison unit 550; the pair-swap switch unit 540X selects from the data associated with the four wire-pairs data that should be switched to

- 5 line X and sends the data down line 542X to the descrambler seed and symbol comparison unit 550; the pair-swap switch unit 540Y selects from the data associated with the four wire-pairs data that should be switched to line Y and sends the data down line 542Y to the descrambler seed and symbol comparison unit 550; the pair-swap switch unit 540Z selects from
- 10 the data associated with the four wire-pairs data that should be switched to line Z and sends the data down line 542Z to the descrambler seed and symbol comparison unit 550. The scrambler coefficients are transported to the descrambler seed and symbol comparison unit 550 through line 542S.

The descrambler seed and symbol comparison unit compares the scrambler coefficients with the pair-swap reordered and symbol aligned data for a selected number of cycles. If an error is found, meaning there is a mismatch during these selected number of cycles, the PCS control unit will reload the non-data mode receiver to start the operation of pair-swap and symbol

alignment detection again. If there is no error during the selected number of cycles, the switchboard 357 starts to operate in the switching mode.

[0031] Reference is now made to Figures 5A and 5B to describe the operation of the switchboard in the switching mode. In the switching mode, the switchboard takes as inputs the data part of the EPAM5 encoded data of the input signal from the slicer/encoder 130. After going through selectors 506A-D and 510A-D, data associated with wire-pairs A-D are loaded in the four FIFO buffers 520 respectively. Data corresponding to each sub-symbol, which is 5-bits in size because of EPAM5 encoding, occupies one 5-bit flip-flop in the FIFO buffers 520. The symbol alignment adjustment units 521 aligns the sub-symbols by buffering the faster sub-symbols longer and by jumping the slower sub-symbols through the FIFO buffers quicker in respect to data from wire A, based on the pair-swap and symbol alignment information received from the non-data mode receiver.

10 The aligned sub-symbols associated with all four pairs of wires are sent to each of the pair-swap switch units 540W-Z. The pair-swap switch unit 540W selects from the sub-symbols associated with the four wire-pairs sub-symbols associated with wire-pair A and send the sub-symbols down line 541W to the EPAM5 decoder 180; the pair-swap switch unit 540X selects

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from the sub-symbols associated with the four wire-pairs sub-symbols that should be switched to line X and sends the sub-symbols down line 541X to the EPAM5 decoder 180; the pair-swap switch unit 540Y selects from the sub-symbols associated with the four wire-pairs sub-symbols that should be

5 switched to line Y and sends the sub-symbols down line 541Y to the EPAM5 decoder 180; the pair-swap switch unit 540Z selects from the sub-symbols associated with the four wire-pairs sub-symbols that should be switched to line Z and sends the sub-symbols down line 541Z to the EPAM5 decoder 180.

10 [0032] In this manner, the switchboard performs symbol alignment and pair-swap reordering on data from the four pairs of wires in one pass. Referring back to Figure 1, the aligned and pair-swap reordered sub-symbols associated with the four pairs of wires arriving at the EPAM5 decoder 180 are EPAM5 encoded and are 5 bits per each sub-symbol. The

15 Encoder expands the 5 bits per sub-symbol to a 9-bit format including neighborhood information for application to the Viterbi decoder 190. By using the EPAM5 encoding, 5 bits instead of 9 bits per sub-symbol are passed through the pair-swap and symbol alignment module 150, and the FIFO buffers 520 in the switchboard 357 can be made much smaller.

Therefore, power consumption and hardware space for the digital receiver 100 are significantly reduced in accordance with the present invention.